Experimental Study on Ozone Production under 50Hz Corona Discharge Used for Faults Diagnostic

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Abstract. Air is one of the most widely used insulation medium in power systems. However, up to now there is no any existing gas analysis method used for fault diagnostic based on air by-products detection and analysis. In this paper, a new discharge diagnostic method — gas analysis method based on air by-products (ozone and NOx) is proposed. Firstly, the chemical reaction of air under discharge is analyzed; then a typical partial discharge — protrusion defect discharge is simulated using needle-plane electrodes in a semi-closed test cell. The relations between corona discharge and ozone concentrations are studied. The ozone concentration increases as the maximum PD and applied voltage increase. Meanwhile, the growth rate of ozone concentration is varying against corona discharge under different voltage. These properties imply discharge faults can be detected by measuring and analyzed the gas concentrations.

Introduction

Chemical detect method also called decomposition gas analysis method is widely used in power system to monitor the discharge faults in electrical equipment, having the advantages to be not invasive, not affected by unwanted electrical disturbances. For example, when discharge or overheat happening, the transformer oil will decomposes to small molecules such as H_2, CH_4, C_2H_4, and C_2H_6. And a fault diagnostic method called dissolved gas analysis (DGA) is based on detecting of these molecules [1]. DGA is one of the most effective method to diagnostic the faults in oil insulated apparatus, especially transformers. Based on this method, one can know the operating condition of the equipment and which kind of faults is happening. For SF_6 insulted apparatus, a similar method is also exist [2]. Air is the most widely used insulation material; however there is few study on fault diagnostic method based on the air derivatives such as ozone, NO_x. One knows that there is ozone and other chemical molecules generated under discharge, but few do more research on this. L.Lepine and D.N.Nguyen from Canada measured the ozone distribution inside stator core of an air-cooled hydro-generator and shows ozone measurement can be used to locate partial discharge qualitatively [3][4]. But no intensive study is done both at home and abroad.

In this paper, a needle-plane corona discharge model is built to simulate discharge in air. The PD and ozone concentration are measured using pulse cur-rent method and UV absorption method separately. The relation between ozone concentration and maximum PD capacity, ozone concentration and applied voltage, ozone concentration and detection time are studied. The results show the ozone concentration increases as applied voltage or Maximum PD capacity increases, but with different pattern. Besides, it will take some time for the ozone concentration to become stable. Different applied voltage response to different growth rate. The results imply gas analysis method in air similarly with gas analysis in SF_6 is a potential method to detect corona discharge of electrical apparatus happening in air.

Theory Analysis

1) Generation of air by-products under discharge

A lot of research has been done on how to effectively generate ozone which is used in ozone generator. In these studies, the mechanism of ozone generation in silent discharge of oxygen-fed

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and air-fed ozonisers are studied [5]. As the main process is show as in table 1.

Tab.1 Chemical model of by-product generation during corona discharge

Serial No.	Chemical Reaction	Serial No.	Chemical Reaction
R1	$e+O_2 \rightarrow O+O+e$	R8	$O+NO_2 \rightarrow NO+O_2$
R2	$O+O_2+M \rightarrow O_3+M$	R9	$NO+O_3 \rightarrow NO_2+O_2$
R3	$O+O_3 \rightarrow O_2+O_2$	R10	$NO_2+O_3 \rightarrow NO_3O_2$
R4	$e+O_3 \rightarrow O_2+O$	R11	$NO+NO_3 \rightarrow 2NO_2$
R5	$e+N_2 \rightarrow N+N+e$	R12	$NO_2+NO_3 \rightarrow N_2O_5$
R6	$N+O_2 \rightarrow NO+O$	R13	$N_2O_5 \rightarrow NO_2+NO_3$
R7	$N+O_3 \rightarrow NO+O_2$	R14	$O+N_2O_5 \rightarrow 2NO_2+O_2$

2) Basis of Gas analysis Method

As said in literature [5] the R1and R5 is the initial step involved in the formation of O_3 and NO_x. It means the electron density which stands for PD capacity is a key role that influences the production of ozone and NO_x. At the same time, considering the band energy of O_2 and N_2 the kinetic energy of electrons which stand for discharge intensity will also be reflected by the production or production rate of ozone and NO_x. So there are some relations between the concentrations of ozone and NO_x and discharge parameters. It means the conditions of air by-product can be used to diagnostic the discharge faults of electrical apparatus in air.

Meanwhile, we can also see from table 1 that the O_3 and NO_x will interact with each other and the O_3 will decompose naturally. Besides, in practical application the distance between discharge and sample position, temperature, pressure, humanity and the condition of gas such as gas in closed, semi-closed or open equipment will affect the gas concentration too. So it will be hard to build the relation between by-products concentration and discharge pattern. It is not enough just by measuring the concentration of gas by-products, the growth rate may be much more effective.

For preliminary study, in the following experiment only ozone concentration is measured for gas in semi-closed vessel which is popular in power system. Both gas concentration and growth rate vary with discharges are investigated.

Experiment Setup

1) Experiment Equipment and Circuit

The discharges are generated, at room temperature (about 298 K), between a stainless steel needle-plane electrodes. The needle electrode, connected to the high voltage, is changed for each test. The plane electrode is earthed. Fig. 1and Fig.2 shows the schematic diagram of the corona discharge test setup. The experimental conditions of the test cell and circuit are given bellow.

In the scheme, T is a 150 kVA single-phase non-PD transformer which is controlled by a regulating transformer at the LV side. Z is the current limited resistor. Cx is a cylinder with needle-plane electrodes which is used to simulate the corona discharge. Ck is the coupling capacitor. Mpd is the PD detector. In this study, the conventional method - measurement of apparent charge is employed as the compared to PD measurement method. The TWPD-2C detector is used. F is a filter and it is used to strain the dust in the air. Mo3 is the Ozone concentration detection device Model 106L which is based on UV absorption method and is produced by 2B tech. The Mo3 is connected with Cx with PTFE tube. Cx is a semi-closed cell with both gas inlet and outlet on the bottom cover. The distance between discharge needle and gas inlet, outlet which may influence is ozone concentration is constant in this paper and will be studied in the following research. The gap of needle and plate can be regulated by tuning the plate electrode. The parameters of the test cell are in table 2.

Table 2. Parameters of test cell.

Parameters	D	L	distance between gas inlet and gas outlet	distance between needle and plane
cm	15	80	33	3.0

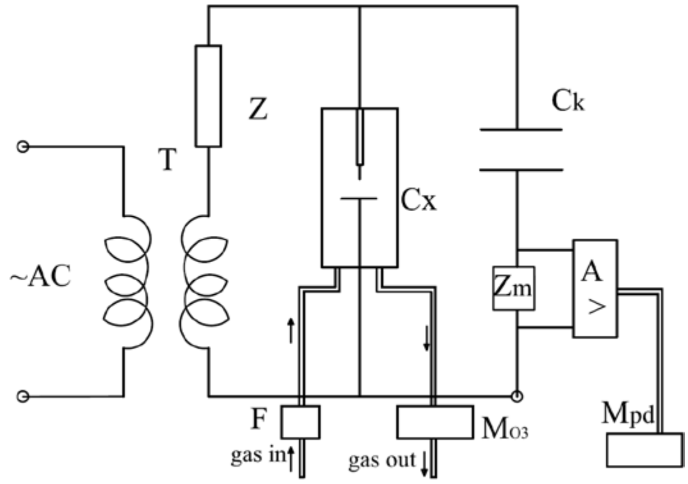


Figure 1. Scheme of the experimental setup

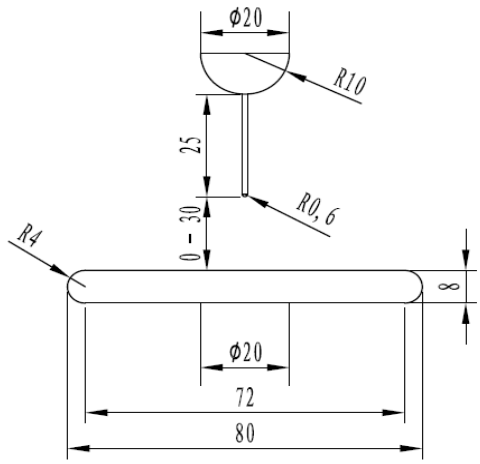


Figure 2. Arrangement of needle-plane electrodes

2) Ozone Concentration Measurements

The most commonly used ozone monitors are based on the UV absorption principle. They measure the absorption by ozone of a UV radiation at 254 nm which is governed by the Beer-Lambert Law. The ozone concentration C is evaluated form the intensity of wavelength measured by a spectrometer.

$$I(\lambda)/I_0(\lambda) = \exp(-\varepsilon Cl) \tag{7}$$

Where l is the path length of the region containing the ozone, $I_0(\lambda)$ is the incident intensity and ε is the absorption coefficient. For a given system, l and are constant and the concentration is directly proportional to the measured absorbance. The measurement is however dependent on the temperature and pres-sure of the gas sample in the cell. Generally, the test result should be corrected to normal temperature and pressure. In our condition, the device can automatically correct the temperature and pressure affection. So the temperature and pressure will not affect the measurement result. However, it is not mean the temperature and pressure does not affect the generation of ozone and other gas.

As said above the ozone concentration is detected by model 106L. It offers a more than adequate detection limit of about 2 ppb with a precision generally better than ±2%. Its sample frequency is below 0.1 Hz. It is mainly used for measurements of ozone in the urban environments. It is connected with test cell using a PTFE tube. The gas in test cell is pump out to the detector. The flow rate is 980 ml/min and is nearly stable during the test.

Normally, ozone and NO_x is also found naturally at ground level, at concentrations of approximately 5-35 ppb and 10-100 ppb separately, depending on the area. It is because human activity can generate ozone and NO_x, particularly in urban environment. In experiment, this influence should be considered.

3) Experiment Process

The following experimental process we consider during experiment:

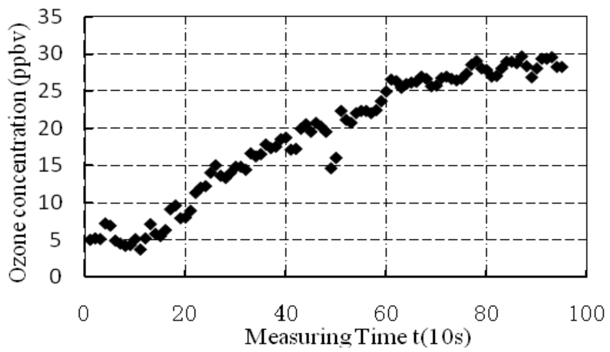
(1) Clean the test cell and needle-plane electrodes. (2) Turn on the Ozone detector and wait for stabilization. Meanwhile make sure the air in the test cell is the same with that in outside. (3) Link on the circuit, turn on the PD detector and wait for stabilization and calibrate it. (4) Put the circuit power on, rise up the voltage. When the voltage increases, the partial discharges appear on the negative half-cycle at first. When the voltage increases sequentially, the partial discharges appear on the positive half-cycle. (5) When partial discharges appear obviously and repeatedly, stop rising up the voltage and start to record the ozone concentration and discharge capacity. The ozone concentration start to increase, record it every 10 s. (6) Wait until the ozone concentration become stable, and then continue to raise up the voltage to a new level, record the data. (7) repeat the experiment for several times. And then tune the gap and repeat the experiment.

Results and Discussion

1) Response Time

Response time is an important factor for condition monitoring device. In this paper, the ozone measurement frequency is 0.1 Hz. The results are obtained in 10 s.

Fig.3 shows the ozone concentration varies with measuring time t when partial discharge initial and the PD capacity is small. As we can see in the figure, the ozone concentration increase not long after corona discharge happens. Fig. 4 gives more proof about this. The relay time is the sum of measurement time which is the time in detecting device and the sample time which is the time that by-products gas transferred from the needle area to the detection device. Besides, measurement result varies a lot because of low concentration and unstable corona discharge. Meanwhile Fig.3 shows it will take some time for the ozone concentration to go stable. Fig.4 shows ozone concentration varies with measuring time t when partial discharge is much bigger. The two figures also show that it will take almost the same time for ozone concentration to go stable under different voltage. This time should be the equilibrium time of ozone in the measurement process and is about 800 s.



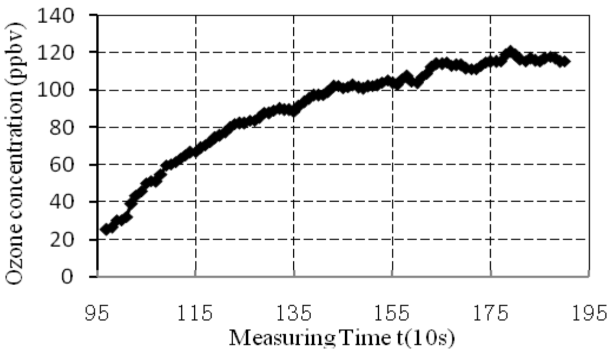


Figure 3. Ozone concentration against time (Applied voltage: 4.7 kV; electrodes gap: 30 mm)

Figure 4. Ozone concentration against time (Applied voltage: 5.6 kV; electrodes gap: 30 mm)

2) Concentration of Gas By-product

In this part, the impact of applied voltage and maxi-mum PD capacity are studied.

Fig.5 shows the ozone concentration goes with maximum PD capacity. As we can see, the ozone concentration increases with PD capacity. The ozone concentration increase slower as PD capacity becomes bigger.

Fig.6 shows ozone concentration goes with applied voltage. As we can see, the ozone concentration increases with applied voltage. The ozone concentration increase faster as applied voltage becomes bigger.

3) Growth Rate of Gas By-product

As we mentioned above, growth rate of by-products is a much useful parameter. Fig.7. shows the ozone concentration under different applied voltage. The ozone concentration in the figure is the real value minus the stable value in lower voltage. The measuring time is the real value minus the last time of the lower voltage. As we can see the line can reflect the growth rate of ozone. It shows Higher applied voltage responses to a bigger growth rate.

Conclusion

In this paper, a new discharge diagnostic method—decomposition gas analysis method based on air by-products, ozone and NO_x, is proposed. Some results are obtained based on experiment.

Some quantitative relation exists based on the chemical reaction under discharge.

The ozone concentration increase not long after discharge happens. But it will take about 800s for ozone concentration to go stable in the experiment.

The ozone concentration increases as the maximum PD and applied voltage increase. The ozone concentration increase slower as PD capacity becomes bigger. The ozone concentration increase faster as applied voltage becomes bigger.

The growth rate of ozone concentration to different corona discharge is different. The higher applied voltage response to a bigger growth rate.

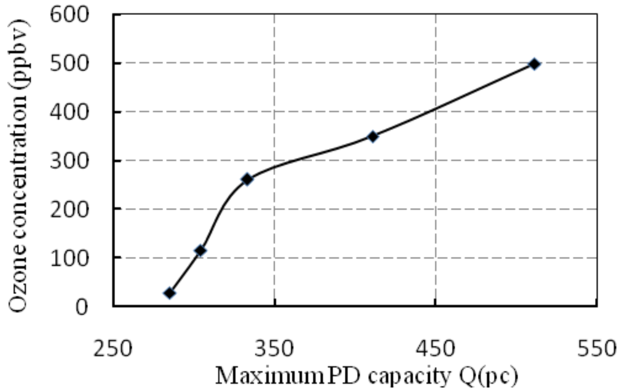


Figure 5. Ozone concentration against maximum PD capacity (electrodes gap: 30 mm)

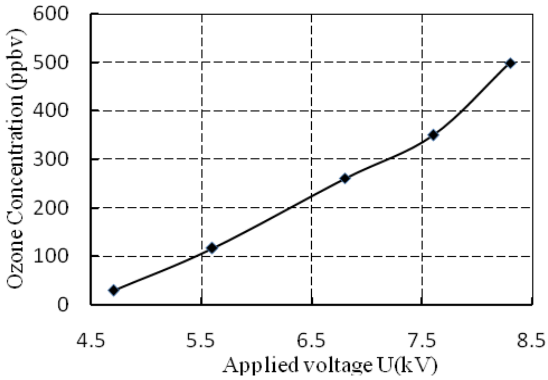


Figure 6. Ozone concentration against applied voltage (electrodes gap: 30 mm)

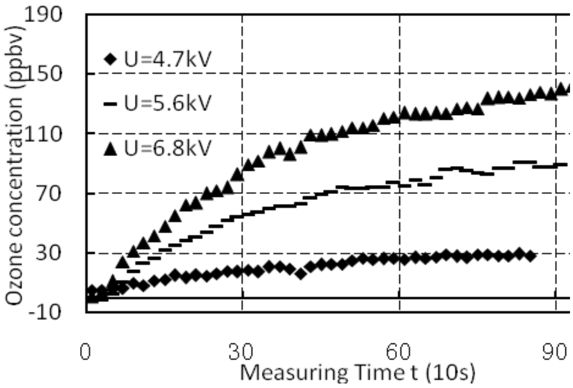


Figure 7. Ozone concentration against applied voltage (Electrodes gap: 30 mm).

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